MULTIFOCAL INTRAOCULAR LENSES

THE PRESENT INVENTION

The present invention is concerned with multifocal intraocular lenses (IOLs) which comprise a lens body having a multiplicity of optical zones wherein an aspheric optical zone is interspersed between add and base power zones.

Bifocal and multifocal intraocular lenses are known in the art and some are currently undergoing clinical trials. While multifocal IOLs are expected to provide good visual acuity for at least two focal points and also greater depth of vision than monofocal IOLs, multifocal IOLs cannot be expected to match the optical performance of monofocal IOLs in terms of image strength and image quality at a given focus. This is because the percent light intensity illuminating the best focused image will be lower for a multifocal IOL relative to monofocal IOL, and the image contrast will thus suffer because of the presence of an unfocused second image While the human visual system is very tolerant of brightness variations, and can extract a great deal of information from low contrast images by virtue of the image processing that occurs in the retina and visual centers of the brain, studies of dependance of visual acuity on illumination levels show that a 100 fold change in illumination causes a 50% decrease in visual acuity at moderate illumination levels while the rate of change in visual acuity is much smaller at very low and very high illumination levels. Thus, the quality of vision which a patient will experience is not solely dependent on the image strength and contrast but is also dependent on the totality of usable visual information presented at the macula.

In U.S. Pat. No. 4,636,211, Nielsen describes a bifocal optic with concentric optical zones of a base power needed for emmetropia or distance vision and an add power designed to provide vision at near or intermediate distances. According to this design, the central portion of the optic constitutes the zone with the add power while the periphery constitutes the zone with the base power. Such an IOL optic may not be suitable for patients with pupil sizes smaller than 2 mm. Kalb has attempted to solve this problem by developing a three zone bifocal lens which provides a central zone for distance vision surrounded by an annular zone embodying the add power for near vision, and the periphery for distance vision. This design tends to minimize the potential loss of distance vision in patients but does not take into account variations in pupil size which occur at varying light levels. Thus, the location and sizes of the various power optic zones have heretofore not been optimized for changes in pupillary diameters which occur as a result of variations in the ambient light levels, nor have the visual tasks which one may expect to perform under various light levels been taken into account in designing IOLs according to the prior art.

Since the area of the optic zone of a given focal length included in the pupillary aperture is proportional to the image strength produced at that focus, visual acuity achieved by a patient who receives an intraocular bifocal optic would be expected to be dependent upon the area of the optic zones at the base and add powers seen through the pupillary aperture. The Kalb design does not optimize for the balance of image strength at different pupil diameters and multifocal optical designs based on diffraction theory do not allow any variation of image strength for near and distance objects as pupillary diameters change. Since the variation of illumination levels is usually smaller indoors than outdoors, variation of pupillary sizes is also smaller indoors than outdoors. Light levels are therefore expected to be at intermediate levels indoors while outdoor light intensity may reach a high level when there is bright sunlight or it may be at a very low level on moonless nights. Since indoor visual tasks mostly require intermediate and near vision, the design of a multifocal IOL should provide the strongest image intensity for near objects at intermediate pupillary sizes. Similarly, outdoor visual tasks usually require distance vision and hence the IOL should be optimized to provide the strongest possible image intensity for distant objects at the extreme values of pupillary sizes. Heretofore no one has taken these factors into consideration in designing multifocal intraocular lenses.

The designs discussed above are bifocal in nature and thus they utilize optic zones of two different focal lengths only. One of these zones is selected to achieve emmetropia of distance while the other provides an add power typically of 2.5 to 4.5 diopter which corresponds to a reading distance of about 11 to 20 inches. This design of lens fails to provide any image intensity for objects at an intermediate distance which requires the use of intermediate power zones or aspheric optics.

According to the present invention it has been discovered that when aspheric optical zones are interspersed between add and base power zones, one obtains a gradual transition in the curvature of the optic surface and avoids abrupt changes in the curvature of the optic. The resulting optic is smooth and lacks transition lines which cause scattering of light leading to the patient's sensation of glare or ghost images. Aspheric zones contribute additional image intensity at both distant and near foci.

The use of aspheric zones in intraocular optics was first described in U.S. Pat. No. 4,769,033 by Dr. Nordan. However, the designs disclosed by Dr. Nordan were not centrosymmentric and were not optimized either for pupillary size or for illumination level variations, nor did they suggest the aspheric zone be placed between the add and base power zones.

More particularly, the present invention is concerned with a multifocal intraocular lens which comprises a lens body having at least five optical zones wherein aspheric optical zones are interspersed between add and base power zones.

According to one embodiment of the present invention a multifocal intraocular lens is produced which comprises a lens body having a plurality of optical zones which comprises add power zones and base power zones and an aspheric optical zone disposed between each add and base power zones thereby providing a gradual transition in the curvature of the optic surface and avoiding abrupt changes in the curvature of the optic.

According to a further embodiment of the present invention a multifocal intraocular lens is produced which comprises a lens body having at least five optical zones, a first zone comprising a central constant power zone for distance vision, a second zone comprising an annular aspheric zone, a third zone comprising a constant power zone for near vision, a fourth zone comprising an aspheric zone to bring the power back to the distance vision level and a fifth zone comprising a con-